Volume porosity and air permeability in knitting fabrics

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Abstract

Main aim of this paper is to find a suitable model that makes possible the prediction of air permeability of a Knitting fabric on the base of its constructional parameters. The methodology: As the constructional parameters of Knitting fabric are considered: gouge of twist factor, yarn count yarns, diameters (or fineness) of yarns and a type of weave structures. This research is focused on clothing woven fabrics of a cotton type. Two variants of so-called cumulative parameter of a Knitting fabric structure are defined and they are applied on the set of Knitting fabrics. Porosities evaluated from empirical analysis and basic knitting wefts structural parameters (kind of material, yarn diameters and loop length / gouge setts). The cotton single jersey of weft knitting constant set of gouge and varying set of weft and varying yarn fineness are used for predictive model building. the obtained results, this new (EMP-THE) Empirical Theoretical Model of Volume Porosity and air Permeability in knitting fabrics are created end evaluated by the combination of partial of samples, numerical without graphs and suitable criterion expressing the predictive ability, a correlation between calculated values of structural parameters and experimental air permeability values was evaluated. Conclusions, in the first step the principal component analysis of volume porosity and air permeability in knitting fabrics, leading of new factors to the design suitable for end-use.

Keywords: air permeability, Knitting, structure, porosity

1. Introduction

Volume is the amount of space occupied by an object or a material, then volume porosity is the amount of space occupied between loops of knitted fabric, or the amount of space occupied by a three-dimensional object or region of space between loops of knitted fabric, Porosity is the ratio of the total amount of void space in a material to the bulk volume occupied by the material. Fabric porosity is an important parameter in assessment of clothing comfort and physical properties of technical textiles. [15, 10, 9, 14]. Several studies have been carried out to analyze the dimensional properties of knitted structures with prevailing these from Chamberlain (1926) [6], Peirce (1947) [19], Leaf and Glaskin (1955) [17], Doyle (1953) [8] and Munden (1960) [18]. These studies have presented either formulated geometrical models consisting of known curves, for example circular arcs and straight lines, or the results of measurements that have been carried out on a series of knitted structures (Demiroz and Dias, 2000) [7]. The present work focuses on the estimation of the geometrical characteristics of a single jersey knitted fabric structure supporting the maximum possible accuracy in order to ensure the numerical modeling success by new equations with experimental on contact analysis.

1.1 Weft knitted structure porosity

Plain weft knitted parameters structure such as the courses per unit length, wales per unite length and loops density, the effect of loops length, and yarn liner density on volume pore size as a basic elements of a knit fabric structure is the loop intermeshed with loops adjacent to it on both sides and above and below it,

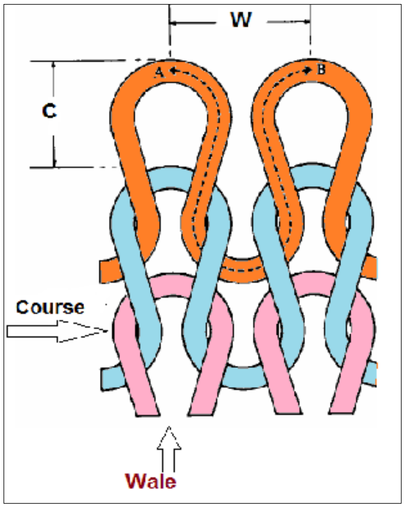

Fig 1: Representation of a plain weft knitted structure. [5]

Where: Wales/cm = 1/w=w, Courses/cm =1/C= c, Loop length = AB= /mm, Loops/cmcm2 =S

Then characterize a pore within loop, which is the unit cell of a plain knitted structure, between the fiber of the yarn in the loop, and the calculated from measurement of fabric thickness with a thickness gauge and yarn diameter as in the following:

$$R' = t/4 \quad (1)$$

Since, $R = \sqrt{R' R''}$ (2)

$$R'' = R^2/R^1 \quad (3)$$

And loop length as the Peirce equation [19]:

$$l = 2/c + 1/w + 5.9\,d \quad (4)$$

Where;
$l = length\ of\ yarn\ on\ loop (cm)$
$c = number\ of\ courses\ per\ cm$
$w = number\ of\ wales\ per\ cm$
$d = dimeter\ of\ yarn\ (cm)$
S, the number of loop/cm^2 of fabric or loop density is defined as follows:

$$S = c\ x\ w \quad (5)$$

We can calculate volume of free space (cm^3), inter-yarn, 1 cm^2

$$Fabric = 1x1xt - \mathrm{Sl}\,\pi R^2 = t - SlSl\pi R^2 \quad (6)$$

Where *t* is fabric thickness, area of free space (cm2) in 1 cm2

$$Fabric = \frac{t - \mathrm{Sl}\,\pi R^2}{\mathrm{t}} \quad (7)$$

Since S is the number of loops in 1 cm2, the area of open space within one loop can be given as follows:

$$Area\ of\ open\ space\ within\ one\ loop = \frac{t - Sl\,\pi R^2}{tS} \quad (8)$$

The pores in a fabric are not circular, however, if the area occupied by a pore is transformed to that of a circle, one can estimate pore radius by the following:

$$Pore\ radius\ = \sqrt{\frac{t - Sl\pi R^2}{\pi t S}} \quad (9)$$

So loop length and yarn diameter incising pore size values decreases, As indicated by equation of The linear density (tex) of a yarn can be given as follows:

$$T = \frac{\pi \mathrm{d}^2}{4} P_y 10^5 \quad (10)$$

Where: *T* is the yarn linear density (tex), *d* is the yarn diameter (cm) and ρy (g/cc) is the yarn, density. Peirce used a value of 0.909 (g/cc) for ρy for cotton yarn. And yarn diameter, *d*, can be shown to be as follows:

$$d = \sqrt{\frac{4T}{\pi P_y 10^5}} \quad (11)$$

When the knitted fabric is treated as a three-dimensional formation, void spaces (pores) can be situated in the fibers, between fibers in the yarn, and between loops threads in the fabric. For these last pores, the term “macrospore” is also used. As textile materials, fabrics knitted structures, the most exactly determined inner geometric model of a porous structure in form of a tube like system, where each macrospore has a cylindrical shape with a permanent cross section over all its length [16]. the density loops in knitted fabric is usually greater than the gouge density; the elliptical shape of the pore cross section is used to represent the situation of *compact force* [13], to compare woven fabric with porosity, a lot of models for description of porosity in woven fabrics distinction can be made among porosity between yarn, an inter-yarn porosity, and porosity between fibers inside yarn, an inter-yarn porosity, from the point of view of an air permeability evaluation. Permeability of porous materials depends very strongly on the morphological structure. Due to the complexity of the fiber architectures and the lack of an adequate mathematical model, many researchers continue to determine permeability experimentally. The main aim of theoretical analysis of volume porosity and air permeability of textile materials is usually to find relationship between an air permeability and structure of knitted fabrics. A knitted fabrics structure is in this case usually represented by its porosity. For a determination of the porosity, a number of theoretical and experimental methods exist. then the porosity indicates how much air a knitted material contains of loops densities distribution for a description of physical properties of knitting fabrics throw a configuration of pores in knitting fabrics (the pore size, shape, arrangement etc.) are very important. We are develop a method to predict the volume porosity by equations analysis as a theoretical model, which used as empirical to predict the volume porosity and air permeability and radius of capillaries of weft knitted spacer fabric based on the geometrical parameters and they found that the porosity and capillary radius of weft knitted spacer fabric influenced by the number of spacer yarn. In this work which can be used to handmade calculate the porosity of plain weft knitted fabric is developed. Requires only few input parameters to generate 3D geometrical model of a plain weft knitted fabric. Comparisons of volume porosity of plain knitted fabrics are made between results obtained from experimental work.

2. Materials and Methods

In this work a plain weft knitted fabrics made with different yarn (19.6, 14.7tex) of acrylic fibre, Twist factor 2.25, were used in order to evaluate the effectiveness of the developed. In case of staple fiber yarn intra yarn porosity was also considered in the calculation of porosity. Table 1 shows the fabric specifications of plain weft knitted fabrics of circular knitting machine (Paolo Orizio), gouge 28/inch, Wales/cm = (1/w=w) = 10 per cm on machine were fabrics described. In a research, the porosity of plain weft knitted fabric is expressed laboratory of consolidation fund at Alexandria Egypt for and air permeability of textiles fabrics ASTM D737-96 [4], and the Stiffness, weight, and Thickness tests have been carried out for textiles research labs, in faculty of Specific Education, Kafrelsheikh University, Egypt. According to ASTM D 1388 – Standard test method for stiffness of fabrics [2], and ASTM D3776 / D3776M – 09a Standard Test Method for mass per unit area (weight) of Fabric [3, 1], by using ElNashar Digital Tests Methods for weight, durability, stuffiness, strength and elongation for fabrics, ASTM D1777 – 96(2007) Standard Test Method for Thickness of Textile Materials [1], by using ElNashar Digital Thickness Test Methods

3. Result and Discussion

Modified 2D model of porosity, in knotting fabrics includes partly a 3D structure of pores. A various pores type does not show the same relationship between a projected and real effective area opened for the flow. The influence of the pores was described with loop basic unit cells. Each type of knitting fabric can be described by the following pore type. The structure parameters of uncut loop (densities of loops, basic structure of loop; linear density of loop; degree of loop ratio of uncut the loops, material of loop. were carried out on single-jersey knitting fabrics, as shown in table (1) which were constructed according to the setting theory. All samples before the measurements were conditioned in accordance with standard. A correlation between porosity and air permeability of a fabric is very complicated because a structure of knitting changes by influence off machine (linear density) system is possible classified as a horizontal increase of the porosity, removing of free loops are interlaced very closely in single-jersey knitting fabrics, relative removing of yarns cause an increase of its porosity predominantly in a vertical direction. Flowing air cause a move of not interlaced parts of loop floats between vertical wales and the horizontal Courses increase of porosity can result in a considerable increase of air permeability, moisture permeability, and vapor permeability. Therefore an interesting material for different application such as garment and technical end-uses to determine knitted fabric porosity, several methods have been developed (optical methods or those based on liquid penetration, absorption, filtration, airflow, etc.). To find the diameters of warp pile cross-section, **d** the cross-section of yarn as indicated of in the following equation:

d =4.44 (√ Tax count/fiber density) 10^{-3} cm. (12) [16]

Then, we can calculate the weight as the following:

W= π (d/4) L * number of loop threads in knitted fabrics. (13)

Where: W = (weight), L= (length of loop).

3.1. Presentation of the Geometrical Model

The main structural parameters of a single jersey fabric are the course-spacing, the wale-spacing and the thickness of the yarn. The rest of the geometrical parameters required for the complete description of the structure derive analytically from the geometrical parameters. Thus the yarns are represented as homogenous cylinders of constant diameter, with initial restricted contact area between them. in figure 1. And this equation gives us more fitting results, it calculates the volume porosity and inner porosity, especially when use the knitted cloth. This model was constructed to have a geometry complicated enough to see the effect of changing the medium location but simple enough to save computational time. Due to geometric symmetry, four different high-permeable medium locations were examined. The permeability of the Seaman high-permeable distribution medium was used in the simulations as the following calculate the knitted fabrics porosity construction % in regular constructors system with plain structure of knitted fabrics by using the flowing figure and equation:

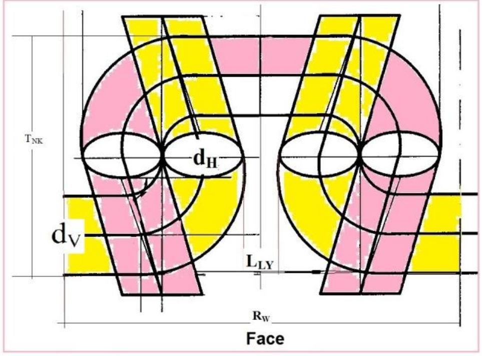

Fig 2: Representation New Model of a plain weft knitted structure.

We calculate volume porosity (V_p) and defined by the following equations**.**

$$VP = \frac{1000\,\pi[2d_v\, d_H\, \gamma\, 4T\, D_Y\,]10/2}{d_{NK}\, T\, \gamma\, \sqrt{[1-0.01\, C_{VH}]100]}} + \frac{L_{LY}\, R_W}{N_{YR}}\, X\, \frac{1}{IFC} \qquad (14)$$

Where symbols description for equation:

V_P = volume porosity,

T_{NK} = thickness of knitted fabrics.

T: Yarn count in Tax system.

C: Crimp for knitted fabrics (vertical- horizontal).

D_y: Density of yarns/cm.

γ: *Scientific

d_V: Vertical Cross section for loop yarn.

(d_H): Horizontal Cross section for loop yarn**.**

L_{LY}: Length of loop yarn "weft" extended between tow intersections in perfect repeat of knitted construction.

R_W: Width of repeat of loop "wale".

N_{YR}: Number of Crouse repeats for loop "weft".

***Scientific** (fiber) density for cotton (1.54)- viscose (1.46)- polyester (1.38) – Acrylic fiber density is 1.17 (g/cm3).

IFC**:** Integration factor construction [IFC (in regular structure) gouge) = 1**].**

IFC = Σ (α X W) / n (15). [15]

Where: α: Balance factor of knitting construction. W: width of stripe (density). n: number of wale width tripes (density). Where: K= C n √ N. For direct system. C= is the constant for material, (0.04126 for Tex.). n = number of course threads per inch. N = yarn count.

3.2. Calculation of the Loop Length [11, 12]

Due to the symmetry of the unit cell the length of the loop is received by the equation 12.

$$L = 4 \cdot arc\,(\Sigma M) + 4 \cdot arc\,(MK) + 2 \cdot arc\,(KP) \qquad (16)$$

Where $arc\,(KP) = 2\theta \cdot k / \sin\theta$ (17)

Basic parameters of a knitting fabric are: loop width Ωr , loop height Δr , loop length ℓpi,

$$\ell pi = \pi \Delta r - \Omega r \qquad (18)$$

Where ℓ is loop length [mm], Ωr is loop width [mm], Δr is loop height [mm]

$$p_1 = 2d\ p_i + d_2 \qquad (19)$$

$$p = 4d\ p_i + 3\, d_2 \qquad (20)$$

Where: p1, space between wale of loop, *P:* Widths repeat. And $d\ p_i$: is pile yarn thickness [mm].

The loop length is influenced by the yarn input tension, Knitting fabric take-down tension, loops interlacing velocity, materials friction in the loop zone, yarn structure and properties, yarn linear density, etc. The knitting fabric vertical density W: is defined by the loop density and the yarn input tension; it changes only slightly with the change of the yarn input tension for conventional yarns for elasticized. The vertical density of the knitting fabric changes with depth change. The loop length increases and simultaneously the vertical density are reduced. Volume porosity and air permeability depending on the materials relaxation process usually comprises shrinking of the plain knitting fabric, Dry relaxation begins immediately after exiting the loop interlacing zone when the tension applied to the loops during the knitting process is reduced. The relaxation takes some time, depending on the yarn material composition, the horizontal/vertical (wales and course) density and the structure of the knitting fabric, and loads applied to the fabric prior to relaxation. The portion of the immediate shrinkage natural materials fabric is wet relaxed during wet after-treatment processes like bleaching and dyeing and additionally during the care process, e.g. laundering and steaming. Theoretically, a knitting fabric changes continually and perpetually tends to attain more stable state than the previous one. The changes are also influenced by the factors like temperature, relative humidity, pressure of materials etc. As the changes are not visible anymore the state is comply with the order. The main structural parameters of a plain knitting fabric are: the head of loop-spacing (P): Widths repeat. the knitting fabric vertical density (w) and the thickness of the loop yarn. The rest of the geometrical parameters required for the complete description of the structure derive analytically from them. The estimation of the geometrical parameters has been based on the assumption of the ideal cotton yarn of knitting fabrics. Thus the yarns are represented as homogenous cylinders of constant diameter for loop and ground, with initial restricted contact area between them. We consider initially the independent parameters c, W, d and in addition the: distance t as it is noticed in figure (2) Geometrical model of plain knitting fabrics structure. Due to the symmetry of the unit cell the length of the loop is received by yarn crimp ratio cross-section change is not neglected it may be assumed, that greater angel of contact will be connected with more important change of yarn cross-section from circular into approximately elliptical, Due to the symmetry of the unit cell the length of the loop is received by the equation.

$$c = \frac{\pi (d)}{180 \sqrt{d_{Vartical}{}^{2} + 2 d_{horizontal}}} + (\pi \Delta r - \Omega r) \cos^{-1} \frac{d}{d_{Vartical}{}^{2} + 2 d_{horizontal}} - 1 \qquad (21)$$

4. Evaluation of the Geometrical Model

The evaluation of the geometrical model is based initially on the comparison of the experimentally defined loop length of a given fabric to the respective calculated by the geometrical model for the same main parameters (*c*, *w*, *D*). The main structural parameters of a fabric can be defined after a microscopic observation and the loop length can be measured using the crimp tester. Table 1 contains the main parameters, the measured loop lengths and the geometrically calculated loop lengths for eight randomly selected fabrics. The error between the calculated loop length and the measured one is considered as the indication of the accuracy of the geometrical model.

Table 1: Element of geometrical porosity and air permeability of a plain knitted loop

N	count tex	Fiber density (g/cm3)	Loops /cm^2 =S	Wales /cm = (1/w=w)	Courses /cm = (1/C= c)	Thickness mm	Areal density (g/m2)	Air permeability	Volume Porosity %	stiffness
1	19.6	1.28	2.25	13.5	15	2.48	145.12	56.3	19.7	41.8
2			3.2	12.5	14.5	2.68	127.37	62.2	18.3	39.8
3			3.8	11.3	14	2.97	95.20	65.4	17.1	37.6
4	14.7		2.24	13.5	16.5	2.55	125.7	57.3	20.2	40.8
5			3.2	12.6	15.5	2.83	111.12	63.5	21.6	37.8
6			3.8	12	14.6	3.2	87.12	67.3	22.9	41.8

These models were suggested includes partly 3-D structure of pores. A various binding type does not show the same relationship between a projected and real effective area opened to a flow. The modified 2-D model of porosity is based on idea that air flows around of yarns not only in a perpendicular direction. The flowing equation, has focused on the creation and the evaluation of a three-dimensional plain knitted fabric geometrical model. The precision of the geometrical model has been cross-checked by using geometrical and mechanical criteria. Especially the mechanical criterion is considering the success of the geometrical model taking in account the final results of the finite element analysis of the structure created. However more realistic models based on a better approach of geometry and material properties will be created in order to investigate the numerical analysis performance of the mechanical properties of knitted fabrics.

4.1. Evaluation of the Geometrical Model

For detection of geometric characteristics of structure of plain knitted acrylic, the method of direct research of inner structure of fabric was used. It was done with help of analysis of soft of fabric samples, introduced in the individual parameters of bent plane knitted fabric were measured to the evaluation of the geometrical model is based initially on the comparison of the experimentally defined loop length of a given fabric to the respective calculated by the geometrical model for the same main parameters (*c*, *w*, *D*). The main structural parameters of a fabric can be defined after a microscopic observation and the loop length can be measured using the crimp tester. Table1 contains the main parameters, the measured and calculation loop lengths and the geometrically calculated knitted loop lengths for six group randomly selected fabrics. The error between the calculated knitted loop length and the measured one is considered as the indication of the accuracy of the geometrical model. Correlation between a structural parameters and air permeability experimental values for all fabrics the air permeability values were measured. and relationships between experimental porosity and air permeability values and structural characteristics of knitted fabrics (determined according to method). were used for measuring of air permeability of knitted fabric. The all parameters of loop structure mentioned above were calculated and for all fabrics porosity and air permeability was measured. Apparently from the table1 and figure 3 that the specific volume of porosity and air permeability are shown constructional parameters of used fabrics and levels of loop. The specific volume is significantly influenced by behavior of the spaces in between structural characteristics values of porosity and air permeability in low level of loop and their deviations from experimental knitted fabrics air permeability values. Evident that in the cases of relatively "opened" fabrics the suggested method gives relatively good results. In the cases very dense fabrics the results (predicated values of knitted fabrics of porosity and air permeability) are not so accurate.

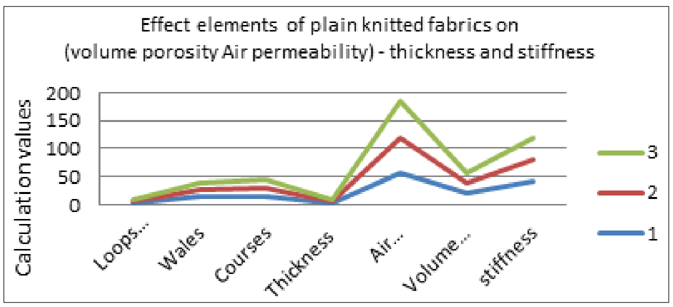

Fig 3: coloration between elements of geometrical volume porosity and air permeability and stuffiness of plain knitted fabrics

5. Conclusion

The present work has focused on the creation and the evaluation of a three-dimensional plain of a warp pile woven fabrics structure fabric geometrical model. The precision of the geometrical model has been cross-checked by using geometrical and mechanical porosity and criteria. Especially the mechanical criterion is considering the success of the geometrical model taking in account the final results analysis of the structure created. However more realistic models based on a better approach of geometry and material properties will be created in order to investigate the numerical analysis performance of the mechanical porosity and properties of a warp pile woven fabrics structure fabrics. The suggested process makes possible prediction of knitted fabrics porosity and air permeability value of plain knitted fabrics, which are characterized by their constructional parameters as are set of wale and course yarns, diameters or fineness of loops of fabrics and by the type of structure. On the base of the area covering value is chosen suitable model for description of knitted fabric structure. The porosity and air permeability value is predicted with use of chosen level and density. Two variants of cumulative parameter of a plain fabric structure were introduced. Knitted fabrics are the preferred structures in athletic wear in which demand for comfort is a key requirement. Heat and liquid sweat generation during athletic activities must be transported out and dissipated to the atmosphere. A key property influencing such behaviors is porosity and stuffiness. Two parameters that characterize it are pore size and pore volume. One of the objectives in this research was to come up with models that can predict interyarn pore size and pore volume for simple weft knitted structures, from fabric particulars, such as courses and wales count, yarn size, stitch density, thickness and other geometrical details of the fabric, which characterize the structure. Such a model was developed that was based on the geometry of the unit cell of a single loop. The experimental work in this thesis involved using a set of 8 knitted fabrics that differed in course count and examining their pore structure and porosity related characteristics. The values of pore size and pore volume were calculated, those of pore size were measured with image analysis and fluid extrusion procedures, and the role of these in determining fluid holding and air and fluid transport properties were determined. The effects of course count and washing on stitch density, stitch length, fabric thickness and pore size are examined in detail.

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